Directional Dependence of the Meissner Effect in Strained Graphene

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We predict that any Meissner-like expulsion of magnetic flux observed in graphene-based systems becomes directionally dependent under anisotropic mechanical strain. The anisotropy manifests as a tensorial magnetic exclusion, with different effective penetration lengths along the principal strain axes. The effect is purely geometric, reversible with strain orientation, and independent of carrier type. It provides a direct, falsifiable signature of anisotropic confinement of a longitudinal vacuum-pressure field (Ψ) in strained graphene.

INTRODUCTION

In conventional superconductors, the Meissner effect is characterized by isotropic expulsion of magnetic flux, reflecting an underlying rotational symmetry of the condensate. Deviations from isotropy are typically associated with crystalline anisotropy or multiband effects and are usually weak.

Within the Quarkbase Cosmology framework, magnetic fields are interpreted as manifestations of vorticity in an underlying longitudinal vacuum-pressure field Ψ. A Meissner-like response corresponds to a coherent Ψ configuration that energetically excludes vorticity from a given domain. Importantly, the rigidity of this exclusion is determined by geometric confinement rather than by microscopic pairing mechanisms.

Graphene provides a unique platform to test this idea. When subjected to anisotropic mechanical strain, the lattice induces an anisotropic effective metric for the confinement of Ψ. As a result, any Meissner-like response in graphene is predicted to become directionally dependent.

THEORETICAL FRAMEWORK

Consider a graphene-based system exhibiting an effective Meissner response, characterized by exclusion of magnetic flux from the interior of the sample. Let the system be subjected to anisotropic in-plane strain such that the principal strain components satisfy $\varepsilon_x \neq \varepsilon_y$.

In this case, the rigidity of Ψ against vorticity becomes anisotropic, and the effective magnetic penetration length acquires a tensorial form,

$$\lambda \;\rightarrow\; \{\lambda_x, \lambda_y\}, \tag{1}$$

with

$$\lambda_x \neq \lambda_y. \tag{2}$$

To leading order, the anisotropy scales linearly with strain asymmetry,

$$\frac{\lambda_x - \lambda_y}{\lambda_0} \propto (\varepsilon_x - \varepsilon_y), \tag{3}$$

where λ_0 denotes the effective penetration length in the unstrained configuration.

EXPERIMENTAL PROPOSAL

The prediction can be tested using established local magnetometry techniques without invoking extreme magnetic fields or temperatures.

The minimal experimental configuration consists of a graphene-based system capable of exhibiting an effective Meissner-like response, subjected to controlled anisotropic in-plane strain via bending, piezoelectric actuation, or patterned substrates. A weak external magnetic field is applied either normal to the plane or rotated within the plane.

Local magnetic field detection can be performed using scanning SQUID microscopy, NV-center magnetometry, or micro-Hall probes.

Two complementary measurement protocols are sufficient. In Protocol A, the local magnetic field $B_z(x, y)$ is mapped across the sample under fixed external field, and effective penetration lengths are extracted along the principal strain axes. In Protocol B, the magnetic field magnitude is kept fixed while its in-plane orientation is rotated by an angle θ, and the expelled or residual magnetic field is recorded as a function of θ.

The key control experiment consists of repeating both protocols with strain removed ($\varepsilon_x = \varepsilon_y$), in which case the magnetic response must revert to isotropy.

PREDICTED RESPONSE

The prediction yields the following signatures:

(i) Magnetic flux exclusion differs along orthogonal in-plane directions aligned with the strain axes. (ii) Local magnetic field measurements reveal different spatial decay lengths for flux penetration along x and y. (iii) For a fixed magnetic field magnitude, rotating the field orientation in the plane produces a periodic modulation of the excluded flux.

In particular, the expelled or residual magnetic field is

expected to follow an angular dependence of the form

$$\Delta B(\theta) \propto \cos 2(\theta - \theta_0), \tag{4}$$

where θ_0 coincides with the principal strain axis.

CONCLUSION

We predict that any Meissner-like magnetic flux exclusion observed in graphene-based systems acquires a directional character under anisotropic mechanical strain. The effect arises from geometric anisotropy in the confinement of a longitudinal vacuum-pressure field and is independent of microscopic pairing mechanisms or carrier properties.

The resulting tensorial magnetic response provides a clear and falsifiable signature of vacuum-mediated rigidity in strained graphene. Observation of a strain-aligned anisotropic Meissner effect would represent strong evidence for the geometric nature of magnetic flux exclusion and for the role of confined vacuum modes in two-dimensional materials.

A detailed theoretical derivation of the strain-induced anisotropy of the Ψ-field will be presented separately.

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